ResBos and RhicBos

Q_T resummation for (un)polarized EW boson production

Pavel Nadolsky

Southern Methodist University

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Objectives of the talk

An overview of physics in

- **ResBos: Res**ummation for electroweak **Bos**ons and their decays in **unpolarized** pp or $p\bar{p}$ collisions
- **RhicBos** = **ResBos** adapted to compute longitudinal single-spin and double-spin asymmetries in **leptonic** decays of γ^*, W, Z in pp collisions
- Single-spin asymmetries in **hadronic** decays of W bosons – a useful measurement **complementary to the leptonic mode**

Interruptions and questions are welcome!

Today's focus is on...

- unpolarized parton distributions:

$$f_{a/p}(x,Q) \equiv f_{a/p}^{+/+}(x,Q) + f_{a/p}^{-/+}(x,Q)$$

- longitudinally polarized parton distributions:

$$\Delta f_{a/p}(x,Q) \equiv f_{a/p}^{+/+}(x,Q) - f_{a/p}^{-/+}(x,Q)$$

- unpolarized cross sections:

$$\sigma = \frac{1}{2}\left[\sigma(p^{\rightarrow}p) + \sigma(p^{\leftarrow}p)\right]$$

- single-spin cross sections ($\neq 0$ if $V-A$ interaction):

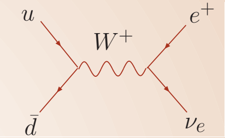
$$\Delta_L\sigma = \frac{1}{2}\left[\sigma(p^{\rightarrow}p) - \sigma(p^{\leftarrow}p)\right]$$

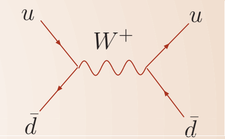
- single-spin asymmetry as a function of W boson rapidity y:

$$A_L(y) \equiv \frac{d\Delta_L\sigma/dy}{d\sigma/dy}$$

Two classes of subprocesses with W bosons

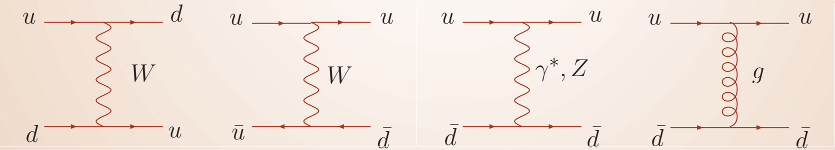
1: Resonant (s-channel) W boson production





- dominant parity-violating process at $Q \approx M_W$
- Leptonic decays: Br($W \to e\nu_e$) $\approx$ 10.8% - RhicBos
- Hadronic decays: Br($W \to$ hadrons) $\approx$ 67%

2: Non-resonant scattering into a dijet final state, mediated by γ^*, W, Z, and g, and interference terms



, etc.

Related publications

On-shell W boson production

1. C. Bourrely, J. Soffer, PLB 314, 132 (1993); Nucl.Phys. B423, 329 (1994)
2. A. Weber, Nucl. Phys. B 403, 545 (1993)
3. P. Nadolsky, hep-ph/9503419
4. T. Gehrmann, Nucl. Phys. B534, 21(1998)
5. M. Gluck, A. Hartl, and E. Reya, Eur. Phys. J. C19, 77 (2001)

Leptonic decay mode

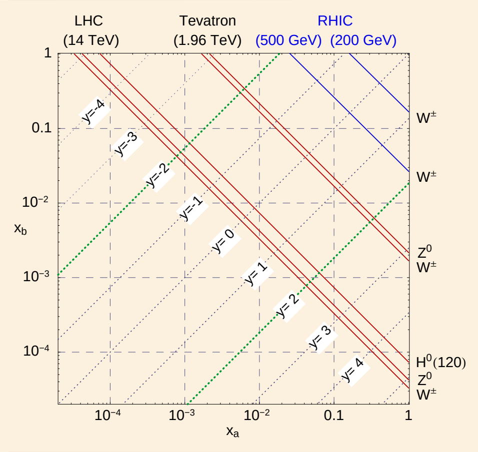
1. B. Kamal, Phys. Rev. D57, 6663 (1998)
2. P. Nadolsky and C.-P. Yuan, Nucl. Phys. B666, 3 and 31 (2003)

Dijet mode

1. H. Haber and G. Kane, Nucl. Phys. B146,109 (1978)
2. F. Paige, T. L. Trueman, T. Tudron, Phys. Rev. D 19, 935 (1979)
3. C. Bourrely, J. P. Guillet, and J. Soffer, Nucl. Phys. B361, 72 (1991)
4. S. Arnold, A. Metz, V. Vogelsang, arXiv:0807.3688; S. Arnold, K. Goeke, A. Metz, P. Schweitzer, W. Vogelsang, Eur.Phys.J.ST 162 (2008)

Leptonic decays

pp and $p\bar{p}$ colliders: accessible momentum fractions



- $W^{\pm}$ at RHIC: access to $x \sim 0.1$ in the experimentally preferred region ($|y| < 2$)
  - valence PDFs at $x \gtrsim 0.1$
  - sea PDFs at $3 \cdot 10^{-2} \lesssim x \lesssim 0.1$

$$x_{a,b} \equiv \frac{M_V}{\sqrt{s}} e^{\pm y}$$

Unpolarized cross sections and their PDF errors

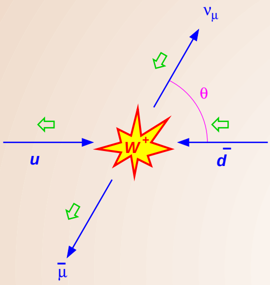
$\mathcal{O}(\alpha_s)$ (=NLO), for 1 lepton generation; CTEQ6 PDFs

Boson	σ (pb)
W^+	124 ± 9
W^-	41 ± 4
Z^0	10.0 ± 0.8

$\sigma(W^+) : \sigma(W^-) : \sigma(Z) \approx 1 \, : \, 0.33 \, : \, 0.08$
(1 : 0.33 : 0.26 in hadronic decays)

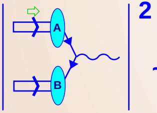
W^+ dominates if $W^+/W^-/Z$ contributions are not separated

$W^{\pm}$ bosons as ideal polarimeters

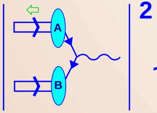


At Born level:

$$\frac{d\Delta_L \sigma(pp \xrightarrow{W^+} \ell^+ \nu_\ell X)}{dx_a dx_b d\cos\theta d\varphi} \propto$$
$$-\Delta u(x_a)\bar{d}(x_b)\,(1+\cos\theta)^2 +$$
$$+\Delta\bar{d}(x_a)u(x_b)\,(1-\cos\theta)^2$$



$\sim u_{-/+}(x_a)\bar{d}(x_b)$



$\sim u_{-/-}(x_a)\bar{d}(x_b)$

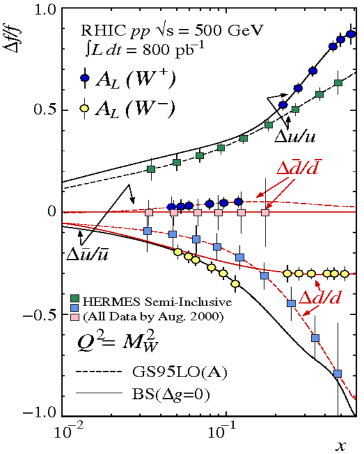
Spin asymmetries in $W^{\pm}$ production are sensitive to the flavor structure of the polarized quark sea

Signature of W boson events: high-p_T charged leptons and $\not{E}_T$

Leading-order $A_L(y)$

$$A_L^{W^+}(y) = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)} = \begin{cases} -\Delta u(x_a)/u(x_a), & x_a \to 1 \\ \Delta\bar{d}(x_a)/\bar{d}(x_a), & x_b \to 1 \end{cases}$$

$$A_L^{W^-}(y) = \frac{-\Delta d(x_a)\bar{u}(x_b) + \Delta\bar{u}(x_a)d(x_b)}{d(x_a)\bar{u}(x_b) + \bar{u}(x_a)d(x_b)} = \begin{cases} -\Delta d(x_a)/d(x_a), & x_a \to 1 \\ \Delta\bar{u}(x_a)/\bar{u}(x_a), & x_b \to 1 \end{cases}$$



- guaranteed large asymmetries at $x \to 1$

Fully differential resummed NLO cross sections

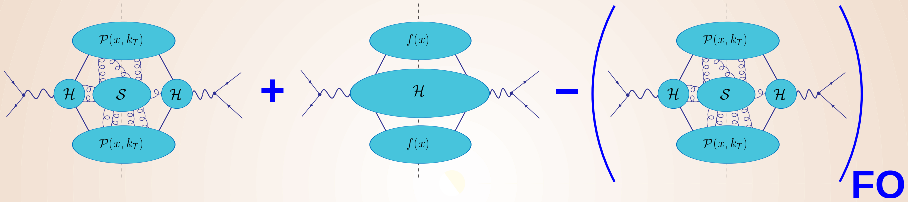
(RhicBos – P. N., C.-P. Yuan, 2003)

- A fast Monte-Carlo integrator implementing q_T resummation at NNLL/NLO
- effects of boson's width and decay, electroweak corrections
- unpolarized, single-spin, and double-spin cross sections
- lepton distributions for realistic acceptance
- available at MSU Q_T resummation portal (http://hep.pa.msu.edu/resum/), together with theory introduction, bibliography, etc.

QCD factorization as a function of q_T

(according to Collins, Soper, and Sterman approach)

Small-q_T term	Large-q_T term	Overlap term
$\Lambda^2_{QCD} \ll q_T^2 \ll Q^2$	$\Lambda^2_{QCD} \ll q_T^2 \sim Q^2$	



- k_T-dependent PDFs $\mathcal{P}(x,\vec{k}_T)$
- Sudakov function $\mathcal{S}(x,\vec{k}_T)$

▷ actually, their impact parameter (b) space transforms

- Collinear PDFs $f_a(x,\mu)$
- hard matrix elements $\mathcal{H}$ of order N

- Truncated perturbative expansion

$$\sum_{k=0}^{N} \alpha_s^k \sum_{m=0}^{2k-1} c_{km} \ln^m \left(\frac{q_T^2}{Q^2}\right)$$

Resummed cross section for $AB \to VX$

$$\frac{d\sigma_{AB\to VX}}{dQ^2 dy dq_T^2} = \sum_{a,b=g,\overset{(-)}{u},\overset{(-)}{d},\dots} \int \frac{d^2b}{(2\pi)^2} e^{-i\vec{q}_T\cdot\vec{b}} \widetilde{W}_{ab}(b,Q,x_A,x_B) + Y(q_T,Q,x_A,x_B)$$

$$\widetilde{W}_{ab}(b,Q,x_A,x_B) = |\mathcal{H}_{ab}|^2 \; e^{-\mathcal{S}(b,Q)} \overline{\mathcal{P}}_a(x_A,b) \overline{\mathcal{P}}_b(x_B,b)$$

$\mathcal{S}$ is the soft (Sudakov) function:

$$\mathcal{S}(b,Q) = \int_{1/b^2}^{Q^2} \frac{d\bar{\mu}^2}{\bar{\mu}^2} \left[\mathcal{A}(\alpha_s(\bar{\mu})) \ln \frac{\bar{\mu}^2}{Q^2} + \mathcal{B}(\alpha_s(\bar{\mu})) \right]$$

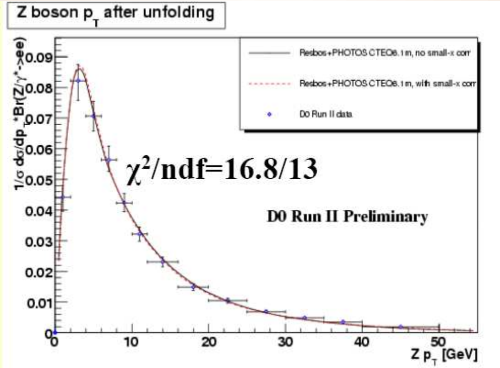
$\overline{\mathcal{P}}_a(x,b)$ are b-dependent PDF's; if $b^2 \ll Q^{-2}$,

$$\overline{\mathcal{P}}_a(x,b) = \sum_c \left[\mathcal{C}_{a/c} \otimes f_c \right] (x, b, \mu_F \sim \frac{1}{b})$$

Y is the difference of the finite-order and overlap (asymptotic) terms

What is in latest ResBos?

- Resummation module for W and Z production – slow
  (**Legacy** — *Ladinsky, Yuan, 1993; Brock, Landry, P. N., Yuan, 2002)*
- Monte-Carlo integration module for W and Z decay and matching of small-q_T and large-q_T terms – fast
  (**ResBos** — *Balazs, Yuan, 1997)*



What is in latest ResBos?

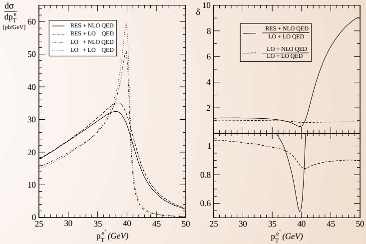
Perturbative QCD contributions

- Finite-order Y term (large q_T):
  - NNLO ($= \mathcal{O}(\alpha_s^2)$) boson-level cross section *(Arnold, Reno, 1989; Arnold, Kauffman, 1991)*
  - parton-lepton spin correlations up to NLO ($= \mathcal{O}(\alpha_s)$)
- Resummed W term (small q_T)
  - NNLL expressions for $\mathcal{S}(b, Q)$ and $\overline{\mathcal{P}}(x, b)$ ($A^{(3)}$, $B^{(2)}$, $C^{(1)}$ coefficients)
  - Two representations for the hard vertex function $\mathcal{H}$ *(Collins, Soper, Sterman; Catani, de Florian, Grazzini)*
    - produce similar predictions for vector boson production
  - $\overline{\mathcal{P}}(x, b)$ for c and b quark scattering in general-mass (ACOT-χ) scheme *(Berge, P. N., Olness, 2006)*

What is in latest ResBos?

Electroweak contributions at all Q_T

- W, Z width in effective Born approximation
- ResBos-A: + final-state QED radiation in W and Z production (*Cao, Yuan*)
  - both W term (2004) and Y term (near completion)
- updated $\gamma^* - Z$ interference New!

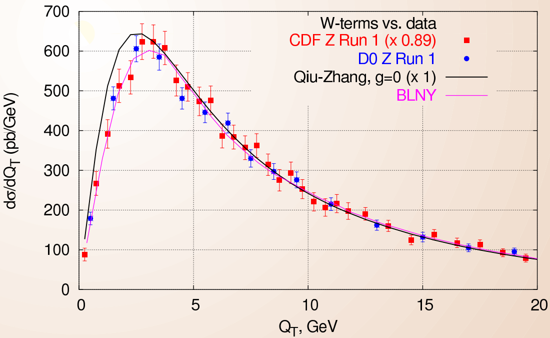


What is in latest ResBos?

Nonperturbative model at $b \gtrsim 1$ GeV^{-1}:

- revised "b_*" approximation + a power-suppressed term $\propto b^2$ *(Collins, Soper, Sterman, 1985; Konychev, P. N., 2005)*
- replaces BLNY model *(Brock, Landry, P.N., Yuan)* used in Tevatron Run-2 M_W measurements

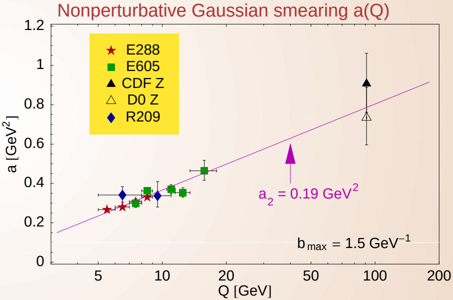
- can approximate a variety of nonperturbative models *(BLNY, Qui, Zhang; Kulesza, Sterman, Vogelsang)*



What is in latest ResBos?

Gaussian $\mathcal{F}_{NP}(b,Q) = b^2\,[0.20 + 0.19\,\ln(Q/3.2) - 0.026\,\ln(100 x_A x_B)]$

- linear $\ln Q$ dependence, in **quantitative** agreement with SIDIS q_T fit and infrared renormalon estimates *(Tafat)*
- small $\sqrt{s}$ dependence
- no tangible flavor dependence
- supports dominance of soft contributions in $\mathcal{F}_{NP}(b,Q)$
- **applies at** $x \gtrsim 10^{-2}$



What is in latest ResBos?

PDF reweighting and ROOT ntuple output

If the central PDF cross section σ_0 and PDF uncertainty $\Delta\sigma^2$ are estimated by generating $\overline{N}$ Monte-Carlo integrator events for each error PDF $f^{(i)}(x,\mu)$ ($i = 0, 2N$), their MC estimates are

$$\overline{\sigma}_0 \sim \sigma_0 + \frac{c}{\overline{N}^{1/2}} \text{ and}$$

$$\overline{\Delta\sigma^2} \sim \Delta\sigma^2 + \frac{c' N}{\overline{N}^{1/2}}$$

- a large factor of $N \sim 22$ in the MC error for $\overline{\Delta\sigma^2}$ due to randomness of event generation for each PDF!
- need N^2 more MC events to evaluate σ^2

What is in latest ResBos?

PDF reweighting and ROOT ntuple output

- PDF reweighting generates the same sequence of events to compute each of $2N$ cross sections
  - $\overline{\Delta\sigma^2} \approx \Delta\sigma^2 + \mathcal{O}(\overline{N}^{-1})$
- In multi-loop calculations, PDF reweighting saves CPU time drastically by reducing slow computations of hard-scattering matrix elements

FROOT: a theorist-friendly interface for Monte-Carlo reweighting

- Written in C, can be linked to standalone FORTRAN/C/C++ programs
- Simple – 170 lines of the code
- Writes the output directly into a ROOT ntuple; no need in intermediate PAW ntuples
- Flexible; new columns (branches) with PDF weights or events can be added into an existing ntuple
- Kinematical cuts, selection conditions can be imposed a posteriori in interactive or batch ROOT sessions
- implemented in ResBos

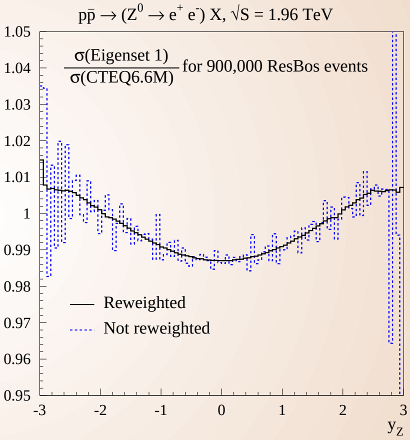
http://www.physics.smu.edu/~nadolsky/projects.html

FROOT: a theorist-friendly interface for Monte-Carlo reweighting

```
// These are the C functions accessible from Fortran.


extern "C" {
  //Initialization of the ROOT file
  void initrootnt_(const char *title, const char *access, int ltitle, int laccess);
  void reinitrootnt_(const char *access, int laccess);
  void addntbranch_(float *element, const char *chtag, int ltag);
  void fillntbranch_(const char *chtag, int ltag);
  int getnumbranches_();
  void rootntoutp_();
  void printnt_();
  void teststr_(const char *str, int lstr);

}//extern "C"
```



RHIC-specific challenges for $W \to \ell\nu$

- $\mathcal{O}(\alpha_{EW}^2)$ process at $x \sim 0.1$
  - relatively small cross sections
  - requires substantial luminosity ($\mathcal{L} = 100 - 400$ pb^{-1})
- Neutrino 4-momentum is unknown
  - Q, y, q_T, missing E_T are unknown
  - PDFs must be deduced from $d^2\sigma/(dp_{Te}dy_e)$ within PHENIX/STAR acceptance, accounting for spin correlations in W decay
    - ◇ can be done using available NLO tools (RhicBos, etc.)

$d\sigma/dy_e$ for charged lepton rapidity y_e

At Born level:

$$\frac{d\Delta_L\sigma(W^{\pm}X)}{dy_e} = \frac{2\pi\sigma_0}{S}\int_{y_{\min}(p_{Te}^{\min})}^{y_{\max}(p_{Te}^{\min})} dy\, \sin^2\theta_e$$

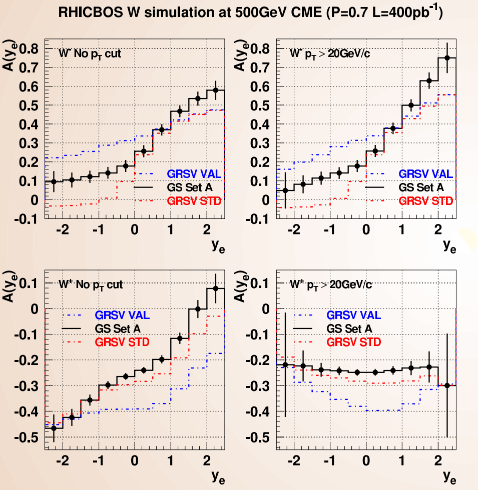
$$\times\left\{-\Delta q(x_a)\bar{q}'(x_b)(1\mp\cos\theta_e)^2 + \Delta\bar{q}'(x_a)q(x_b)(1\pm\cos\theta_e)^2\right\},$$

with $\cos\theta_e = \tanh(y_e - y)$

$W^+ : q = u,\, \bar{q}' = \bar{d}$

$W^- : q = d,\, \bar{q}' = \bar{u}$

$d\sigma/dy_e$ for charged lepton rapidity y_e



- Positrons from $W^+ \to e^+\nu_e$ tend to scatter backwards in the W rest frame$\Rightarrow$
  - sensitivity to $\Delta u(x)$ at $y_e \lesssim 0$, $\Delta\bar{d}(x)$ at $y_e \approx 0$ (at variance with common intuition)
  - manageable, but a bit contrived

Dijet decays

E. Berger and P. Nadolsky, Phys. Rev. D78, 114010 (2008)

Resonant W boson contribution to $pp \to$ jet $+$ jet $+ X$

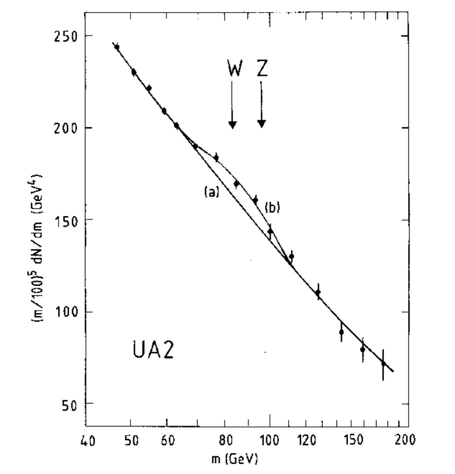
- The hadronic mode is complementary to the leptonic mode:
  - W boson's virtuality Q and rapidity y can be established **approximately** by equating them to the dijet invariant mass and rapidity
  - Contributions mediated by W^+ bosons dominate over W^- and Z^0 contributions; the PDF dependence of $d\sigma/dy$ closely resembles that in W^+ boson production
  - No smearing of PDF dependence by spin correlations in W decays (especially relevant for $\Delta\bar{d}(x,Q)$)

Hadronic mode at RHIC and other colliders

Observation of the hadronic mode at RHIC is much easier than at the Tevatron/LHC, slightly harder than at SppS

- relatively low backgrounds, especially for **parity-violating** A_L
- largest QCD backgrounds are **parity-conserving**; can be subtracted using a side-band technique
- low Q resolution is sufficient (not an electroweak precision measurement as at the Tevatron)

$W \rightarrow$ hadrons at SppS *(PLB186, 452 (1987))*



- $p\bar{p} \rightarrow WX$, $\sqrt{s} = 630$ GeV, $\mathcal{L} = 0.73$ pb^{-1}; $x \sim 0.13$
- 3σ signal in the dijet mass ($m = Q$) distribution
- background/signal$\gtrsim 20$ (RHIC: $\gtrsim 30$; Tevatron: $\gtrsim 570$)
- background is smooth
- can be interpolated from the sidebands in Q and other variables

- Mass resolution $\delta m = 8 - 9$ GeV
- W and Z peaks are not separated

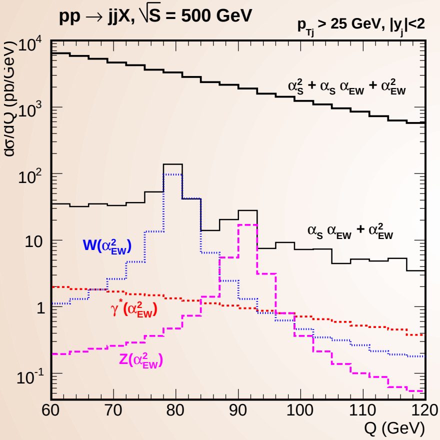
Calculation of the dijet cross sections

- Compute $pp \to \text{jet} + \text{jet} + X$, approximated by $2 \to 2$ exchanges of $V = g, \gamma^*.W^\pm, Z^0$ in the s, t, and u channels; orders α_{EW}^2, $\alpha_s\alpha_{EW}$, and α_s^2
- Cross sections are fully differential in the momenta of two jets; allow acceptance cuts
- MadGraph for generation of cross sections and MadEvent for phase-space Monte-Carlo integration. Programs operate with helicity-dependent scattering amplitudes, but typically the amplitudes are summed over all helicity combinations to produce spin-averaged cross sections.
  - modified MadEvent to evaluate single-spin cross sections (available upon request)

Calculation of the dijet cross sections

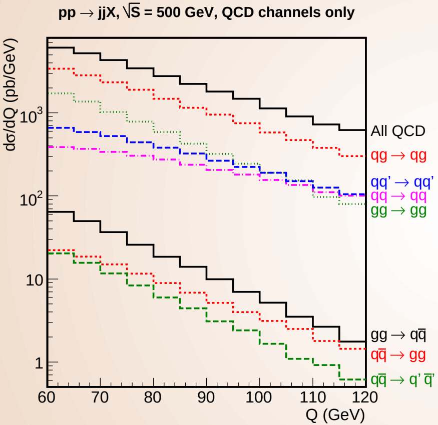
- Include contributions from u, d, s, c, and g
- Factorization and renormalization scales: $\mu_F = \mu_R = Q$
- Impose constraints $p_{Tj} > 25$ GeV and $|y_j| < 2$ to reproduce approximately the acceptance of STAR

Unpolarized dijet mass (Q) distributions



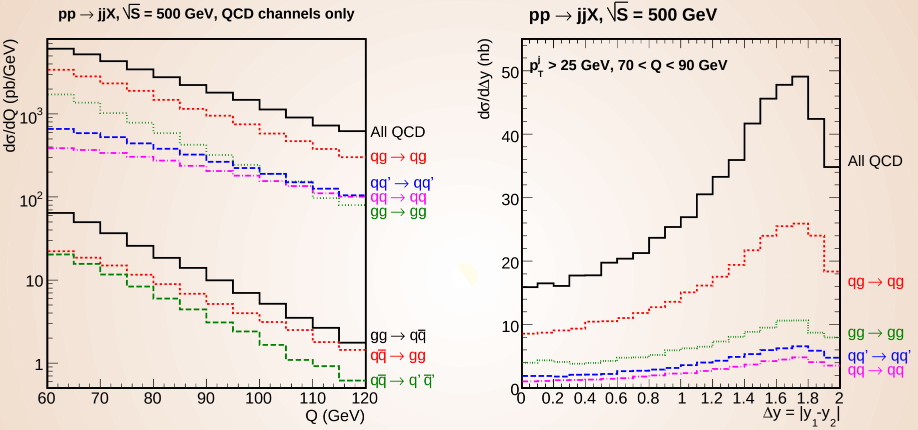
- Continuous event distribution from QCD and electromagnetic scattering (g and γ^*) dominates
- "Signal region" = region in which Q is close to M_W (e.g., $70 \leq Q \leq 90 - 100$ GeV)
- Even in this region, the spin-averaged W and Z contribution is no more than a few percent of the full event rate

Unpolarized cross section: flavor separation



- q stands for both quarks and antiquarks
- qq (qq') stands for scattering of the same (different) quark flavors
- All PV signal has two quark-initiated jets (qq')
- 75% of the background is from $qg \to qg$ and $gg \to gg$ with 1 or 2 gluon-initiated jets

Unpolarized cross section: flavor separation



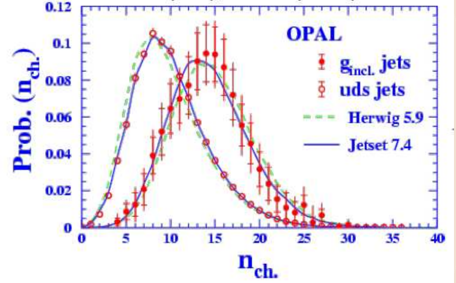
- $\Delta y \equiv y_1 - y_2$ probes dependence on the decay polar angle θ; $\Delta y = 2\tanh^{-1}(\cos\theta)$ at LO
- $d\sigma/d\cos\theta$ and $d\sigma/d\Delta y$ of the $qg,\ gg$ backgrounds are different from those of the qq' signal

Quark-like jets look differently from gluon-like jets

LEP and Tevatron: typical g-like jets have a larger multiplicity and broader jet shapes than u, d, s-like jets

- Similar differences must exist at RHIC
- 75% of the background events contain a g-like jet; $A_L(y)$ is enhanced by a large factor by excluding such events

OPAL (LEP), EPJC11(1999)217



$$\frac{\langle n_{charged}\rangle_{g \text{ jet}}}{\langle n_{charged}\rangle_{u,d,s \text{ jet}}} = 1.51 \pm 0.04$$

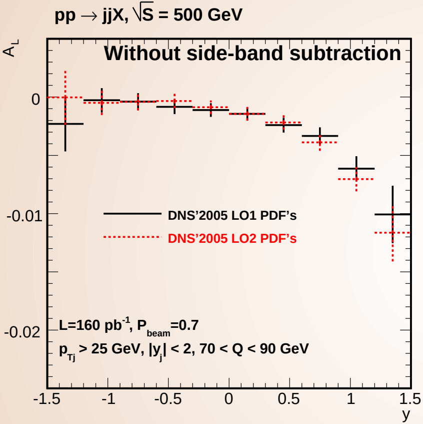
Further details: B. Gary & N. Varelas at 2009 CTEQ Summer school (http://www.phys.psu.edu/~cteq/schools/summer09/), and refs therein

Spin-dependent dijet production

$$A_L(y) \equiv \frac{d\Delta_L \sigma/dy}{d\sigma/dy} = \frac{N}{D}$$

- Parity violation needed to obtain a non-zero N arises solely from qq contributions with intermediate W and Z bosons
- The magnitude of A_L for $70 < Q < 90$ GeV may be enhanced by applying a "side-band background subtraction" to D
- In this calculation, we approximate the "subtracted" D by the $\mathcal{O}(\alpha_s \alpha_{EW} + \alpha_{EW}^2)$ unpolarized cross section

Spin-dependent dijet production

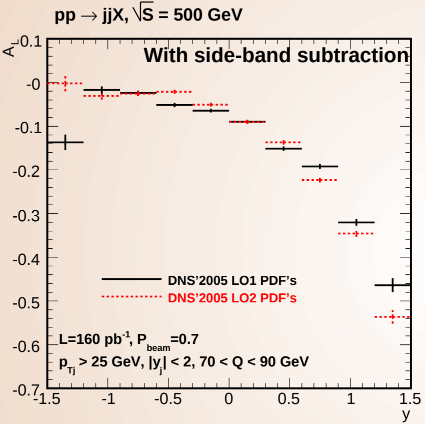


No subtraction

- D is dominated by large $\mathcal{O}(\alpha_s^2)$ terms
- A_L is small
- Different $\Delta f_{a/p}$ cannot be discriminated

Error bars are projected statistical uncertainties for $\mathcal{L} = 160$ pb^{-1}, $P_{beam} = 0.7$

Spin-dependent dijet production



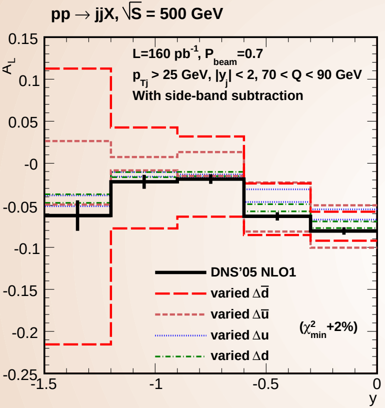
With subtraction

- $\mathcal{O}(\alpha_s^2)$ terms, other non-resonant contributions are measured at $Q < 70$ GeV and $Q > 90$ GeV; interpolated and subtracted from D at $70 < Q < 90$ GeV
- A_L is enhanced; statistical errors remain reasonable
- Sensitivity to $\Delta f_{a/p}$ is improved

Error bars are projected statistical uncertainties for $\mathcal{L} = 160$ pb^{-1}, $P_{beam} = 0.7$

Sensitivity of A_L to $\Delta\bar{q}$

A_L for production of jet pairs, after side-band subtraction



For $y < 0$, pronounced variations in A_L due to the variation of $\Delta\bar{d}(x, Q)$

The black curve corresponds to the DNS2005 NLO PDF set 1. The pairs of other curves contain the ranges of A_L obtained if $\Delta q \equiv \int_0^1 dx\, \Delta q(x, 3.16\ \text{GeV})$ is varied within $\Delta\chi^2/\chi^2_{min} < 2\%$

Discussion

Data-driven search for resonant $W \to$ jet $+$ jet contributions

$A_L(y)$ is most accessible in the signal region:

$$Q = M_W \pm 10 - 15 \text{ GeV}, \; p_{Tj} \gtrsim 25 \text{ GeV}, \; |y_{1j} - y_{2j}| \lesssim 1$$

The measurement can be based on the following strategy:

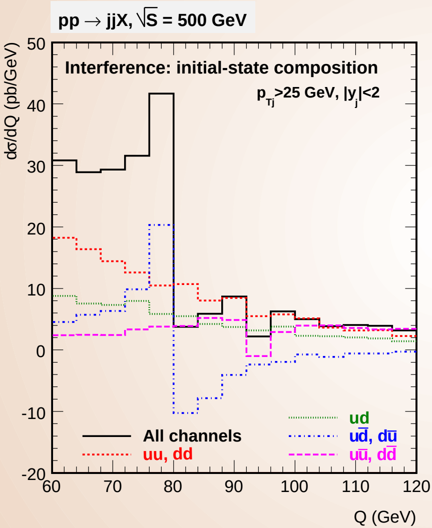
1. Discard events with gluon-like jets (wide, large multiplicity) to the best of one's ability
2. Precisely measure the smooth background outside of the signal region
3. Use this measurement to predict and subtract the background inside the signal region
4. Look for a large $A_L(y)$ at $y > +1$ (driven by a large $\Delta u(x)/u(x)$ at $x \to 1$)
5. Measure moderate $A_L(y)$ at $y < -1$ to constrain $\Delta\bar{d}(x)/\bar{d}(x)$ at $x < 0.1$

Next-to-leading order

- A more precise calculation must include NLO QCD contributions. These increase predicted rates and stabilize hard-scale (μ_F) dependence.
- Backgrounds in the denominator of $A_L(y)$ will be larger
- Comparably large enhancements in the numerator due to $\alpha_s^2\alpha_W$ terms *(Moretti, Nolten, Ross, Phys. Lett. B643, 86 (2006))*
- Predicted magnitude of A_L could remain largely unaffected
- Could lead to a decrease in δA_L, since $\delta A_L \propto 1/\sqrt{N_{unp}}$

Backup slides

Flavor composition of QCD-EW interference in dijet decays

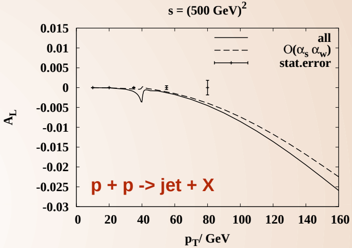


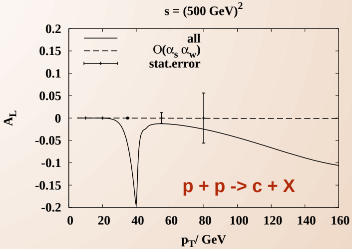
- Large resonant $u\bar{d}$, $d\bar{u}$ contributions cancel when integrated over a Q range centered around M_W
- Smaller non-resonant uu, dd, ud contributions survive

Parity-violating spin asymmetries in polarized pp scattering with hadronic final states

Arnold, Metz, Vogelsang, arXiv:0807.3688; Arnold, Goeke, Metz, Schweitzer, Vogelsang, Eur.Phys.J.ST 162 (2008)

- Focus on **1 jet-inclusive** $d^2\sigma/dy_j dp_{Tj}$ (inclusive in Q, y_{2j}, y)
  - our **2 jet-inclusive** calculation imposes lower cuts both on Q and p_{Tj} (better background rejection)
- Estimates are made without side-band subtraction $\Rightarrow$ $|A_L| < 2-3\%$





Parity-violating spin asymmetries in polarized pp scattering with hadronic final states

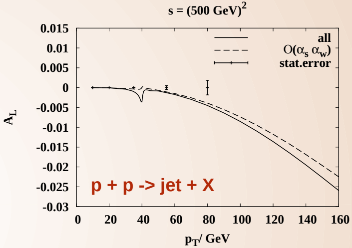
Arnold, Metz, Vogelsang, arXiv:0807.3688; Arnold, Goeke, Metz, Schweitzer, Vogelsang, Eur.Phys.J.ST 162 (2008)

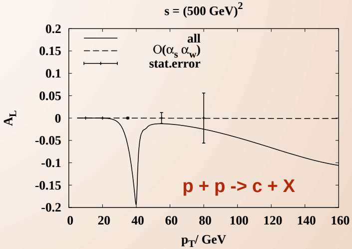
Backgrounds can be suppressed by requiring a final-state c quark

☺ A_L increases

☹ event rate is reduced by experimental charm tagging (not included here)

(?) net effect needs further study

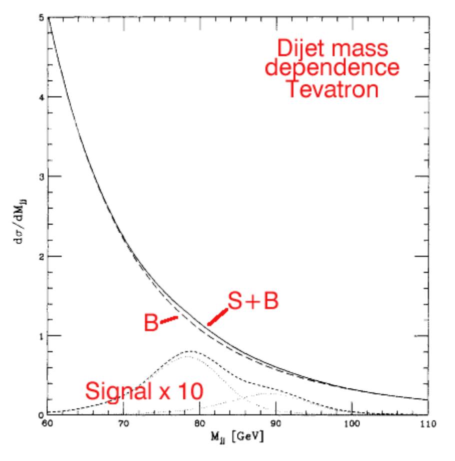




Our MadEvent calculation allows selection of final-state c quarks or other particles (leading pions, etc.) to suppress the QCD background

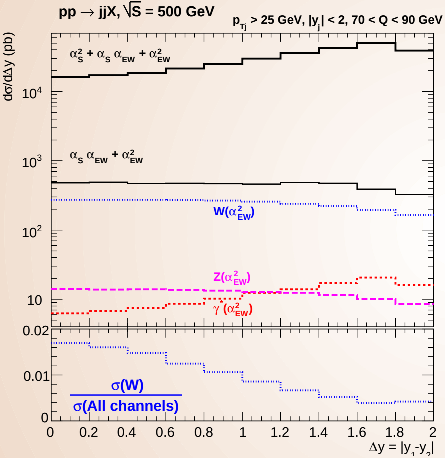
$W \to$ hadrons at the Tevatron

(J. Pumplin, PRD45, 806 (1992); U. Baur et al., hep-ph/0005226)



- $p\bar{p} \to WX$, $\sqrt{s} = 1.8$ TeV, $x \sim 0.04$
- background/signal≈ 570
- After an angular cut in the W rest frame: background/signal$\approx$255 $QQ/W \approx 22$, $QG/W \approx 101$, $GG/W \approx 132$
- mass resolution $\delta M_{jj} \geq 0.5$ GeV
- of no use for M_W measurement, unless the gluon background is drastically reduced

Distributions in Δy - difference of jet rapidities



Full $\mathcal{O}(\alpha_s^2 + \alpha_s\alpha_{EW} + \alpha_{EW}^2)$ cross section is peaked strongly at large $|\Delta y|$. The $\mathcal{O}(\alpha_{EW}^2)$ and $\mathcal{O}(\alpha_s\alpha_{EW} + \alpha_{EW}^2)$ cross sections have flatter Δy dependence

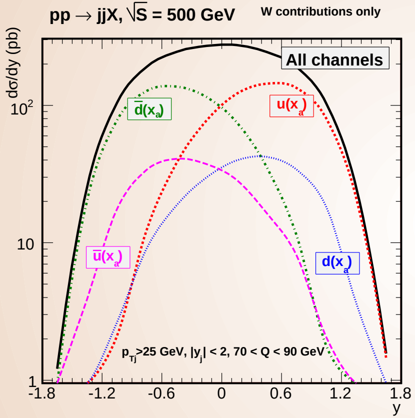
Leptonic decay mode

$pp \to (W \to \ell\nu)X$ **at** $\sqrt{s} = 500$ **GeV**

- "Theoretical clean" process
  - mostly $u\bar{d} \to W^+$ or $d\bar{u} \to W^-$; small contributions from s, c, b, g
  - relatively simple QCD and EW higher-order contributions
- Flavor sensitivity through the CKM matrix
- good sensitivity to **quark sea** at scales of order M_W (pp scattering)
- **single-spin** measurements **cleanly** constrain Δq, $\Delta\bar{q}$
  - complications of low-Q (SI)DIS are avoided

Quark flavor composition, unpolarized

W^+ and W^- contributions

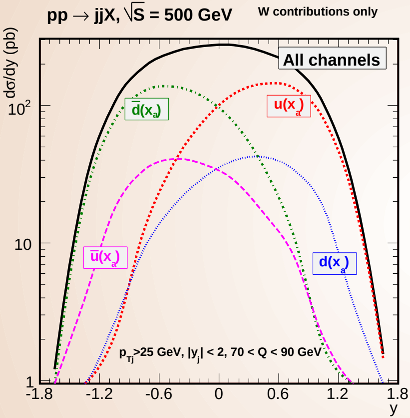


- Figure identifies contributions proportional to $u(x_a)$, $\bar{u}(x_a)$, $d(x_a)$, and $\bar{d}(x_a)$
- The combined $W^{\pm}$ cross section is dominated by
  - $u(x_a)$ contributions at $y > 0$
  - $\bar{d}(x_a)$ contributions at $y < 0$

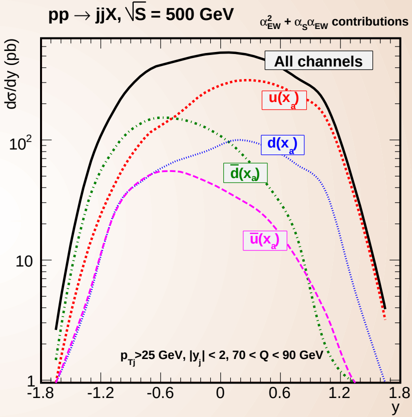
— as in resonant W^+ production

Quark flavor composition, unpolarized

W^+ and W^- contributions



$\mathcal{O}(\alpha_s\alpha_{EW} + \alpha_{EW}^2)$ contributions



Sensitivity to $\bar{d}$ at $y < 0$ is preserved despite QCD-EW interference, after integration over $70 < Q < 90$ GeV